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Self-presentation

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My studies at University College Dublin, and at the Regia Università di Roma were chiefly mathematical with a bias towards mathematical physics. On returning to Ireland in January 1942 I found that the Dublin Institute for Advanced Studies had been established just one year previously, that it included a School of Theoretical Physics with Erwin Schrödinger as its director, and that Walter Heitler had recently joined it. My research effort for a number of years was to be greatly influenced by Schrödinger and by Heitler.

At this period Schrödinger was very interested in the nonlinear electromagnetic theory of Gustav Mie, who described the field *in vacuo* by an electric displacement vector which is not just a constant times the electric intensity, and a magnetic induction which is not just a constant times the magnetic intensity, as it is in Maxwell's theory. During the 1930's Born, Infeld and Schrödinger published papers on this nonlinear theory. A consequence of the nonlinearity was that two electromagnetic rays would scatter each other.

Schrödinger had shown that the nonlinearity would give to Planck's law for black-body radiation a correction of only 1 per cent at a temperature of 4×10^{10}K. He suggested that I examine the mutual scattering of electromagnetic rays by employing the formalism of quantum field theory. It was found that the mutual scattering effect was too small to be observed then (1943). In fact the possibility of detecting the mutual scattering of light rays has been raised quite recently by V.J. Ding and A.E. Kaplan (Phys. Rev. Lett **63**, 2725, 1989). However some doubt about the validity of their calculations has been expressed by G.W. Ford and D.G. Steele (unpublished).

In 1942 Schrödinger gave a set of seminar lectures on general relativity which led him into the quest of finding a unitary field theory that would provide a set of equations describing both electromagnetic and gravitational phenomena. Having found such a set of equations he asked me to look into its implications for the possible magnetic field of a planet. Since on account of World War II no calculators were available, I found myself using logarithmic tables to seven decimal places.

In the limiting case where gravitational forces are neglected Schrödinger's unitary theory led not to Maxwell's equations but to the Proca equations

$$\underset{\sim}{H} = \text{curl}\ \underset{\sim}{A}\ , \quad E = - \dot{\underset{\sim}{A}} - \text{grad}\ V$$

$$\text{curl}\ \underset{\sim}{H} - \dot{\underset{\sim}{E}} = - \mu^2 \underset{\sim}{A}\ , \quad \text{div}\ \underset{\sim}{E} = - \mu^2 V\ ,$$

which give a finite mass of the photon. From the observed accuracy of the law of Gauss for the earth's magnetic field it was inferred that the Compton wave length associated with the finite mass of the photon should be greater than 15,000km. I understand that data from the Voyager fly-past of Jupiter in 1979 reduced the figure 15,000km by several orders of magnitude, and so there is now disagreement with the Schrödinger theory.

During this period Heitler, who already in 1936 had published the first edition of his masterly book on the quantum theory of radiation, became very interested in the particle having a mass of about 200 electron masses. This particle, then called the meson, had been found by Kunze in cosmic radiation. At this time cosmic rays were the only source of high-energy elementary particles. It was presumed that the cosmic ray meson was the carrier of nuclear forces proposed by Yukawa and that it was analogous to the photon which is the carrier of electromagnetic forces. Actually we now know that the cosmic ray meson is not the carrier of nuclear forces.

Heitler working in collaboration with two research scholars J. Hamilton and H.W. Peng devoted himself to the study of the production of mesons by proton-proton, proton-neutron and neutron-neutron collisions and this group of researchers applied their results to the production of cosmic ray mesons. Since the proton, like the electron, has spin ½, they employed Dirac's equation for the proton. I raised the objection that this procedure implied that just as the electron has an antiparticle - the positron - so also the proton should have an antiparticle, then called the negative proton and now called the antiproton. No such particle had then been detected and Heitler suggested that I should try to find out why this was the case. His suggestion gave rise to a sequence of papers spanning the period 1945 (that is, 10 years before the experimental discovery) until 1963. During the period 1949-1952 I also made some calculations related to the self-energy and self-charge of elementary particles.

The success in the 1960's of the application of Lie algebras to the classification of elementary particles led me to turn my attention to weight diagrams and Young tableaux. From this I went into a study of Schur functions and in particular into investigating difficulties that may arise in the multiplication of Schur functions.

After a few years dealing with pure mathematics I found myself anxious to return to physics. Many of the subsequent investigations were based on stochastic differential equations. Indeed the stochastic rotation operator played a central role in the discussion of certain relaxation processes. Let us first take the case of dielectric relaxation. We consider a rigid polar molecule with no special symmetry that is being tossed around in a nonpolar liquid environment and we denote by $R(t)$ the operator related to the rotation of the molecule from its initial to its final orientation. Then $R(t)$ satisfies an equation

$$\frac{dR(t)}{dt} = - i(\underset{\sim}{J} \cdot \underset{\sim}{\omega}(t))R(t) ,$$

where $\underset{\sim}{J}$ is an infinitesimal generator of rotation and $\underset{\sim}{\omega}(t)$ is the angular velocity of the molecule. The complex permittivity may be obtained from the ensemble average $\langle R(t) \rangle$ and this is found from the above equation and the value of $\langle \omega_i(t)\, \omega_j(s) \rangle$. To express the results in a convenient form it was found helpful to employ a mathematical method due originally to Krylov and Bogoliubov.

It will be known to some of the audience that Debye solved the dielectric relaxation problem for a spherical molecule by neglecting the inertial effects of the molecule. However this led to an absorption curve $a(\omega)$v.ω which had a horizontal plateau for high frequencies. This is at variance with experimental findings. By including inertial effects and applying Langevin theory

Scaife, Ford, Lewis and I got rid of the Debye plateau. However the theoretical absorption curve is far below the experimental curve which shows Poley absorption. In order to explain this discrepancy Professor A.I. Burshtein of Novosibirsk and I have recently been working on a model for far infrared absorption based on Mori theory and the supposition that molecular collisions are not instantaneous. So far the comparison with experiment is encouraging but we are still pursuing our investigations.

The rotation operator technique has also been applied to nuclear magnetic relaxation in liquids. This has been studied for various relaxation mechanisms, namely, dipolar interaction, quadrupolar interaction, anisotropic chemical shift, spin-rotational interaction, and also for various molecular shapes, namely, the sphere, linear rotator, circular plate, symmetric rotator, asymmetric rotator. It is found <u>inter alia</u> that for nuclear magnetic relaxation processes inertial effects are negligible for the present state of experimental accuracy.